UNDERSTANDING THE ACTIVE 41-INCH ROD ANTENNA

Obtaining accurate low frequency E-field readings using an active 41-inch rod antenna requires a clear understanding of the physics of the rod and its counterpoise, the influence of the pre-amplifier, the antenna factor, and the use of the proper calibration techniques.

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BACKGROUND

Beginning in 1948, 41-inch rod antennas came into common use for measuring low frequency E-field emanations. This type of antenna is most commonly used inside a screen room, where its relatively small size makes it convenient to use. The first rods used passive networks to transform the signal imposed on the rod into a 50-ohm unbalanced output on a coaxial cable. Typically, a series of pot core inductors was placed at the base of the rod. These elements were designed to be low Q and to resonate at different frequencies. This produces a band of relatively flat frequency response just above the resonant frequency.

These units worked well, but had their shortcomings. Each unit had many band settings in order to cover the frequency range of the antenna. The user was constantly changing band settings during a typical test. Also, loss of signal through the circuit tended to be fairly high. Typical antenna factors were anywhere from 10 to 60dB, depending on the frequency of interest. More recently, active networks have been used to transform the voltage at the base of the antenna element into a signal on a 50-ohm coaxial cable (Figure 1 shows a modern active 41-inch rod antenna).

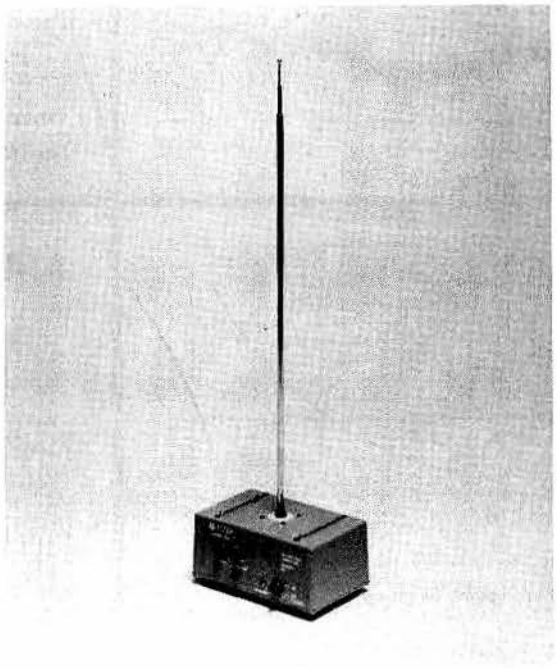

Figure 1. A Typical Modern, Active 30 Hz to 50 MHz 41-Inch Rod Antenna.

THE ROD

There are three factors which are of primary interest in understanding a rod antenna: its effective electrical length, the impedance it presents to the measurement system, and the interaction of the rod with the ground. This discussion deals only with an electrically short antenna element.

By *electrically short* is meant an antenna which is designed to have the physical antenna element short when compared to the wavelength of the highest frequency in measurement range. The current distribution on any rod antenna will be sinusoidal. If a rod is short enough with respect to the wavelength being measured, that distribution will approach a linear distribution and may be assumed to be linear for all practical purposes. The linear current distribution will allow for linear scaling of the rod length. If the rod length is reduced by half, then the received voltage will be reduced by half. The 41-inch rod is approximately a meter long. Electrically, it then is a half-meter long. The assumption of linearity will remain accurate at least to one-eighth wavelength. At this point, some resonance behavior is possible. A rod which is electrically a half meter is one-eighth wavelength at 75 MHz. Similarly, a 50-inch rod is one-eighth wavelength at 59 MHz. In order to keep the response of the unit linear and avoid resonance behavior, the antenna pre-amplifier is limited to roll off before these frequencies have been reached. However, this avoidance of possible resonance carries the penalty of 6dB on the antenna factor. Since field strength is measured as volts per meter, the measurement must be normalized to one meter. This means that 6dB must be added to a reading taken with a rod which is electrically a half-meter.

The second factor which is of concern *is the impedance the rod pre-*

sents to the measurement system. The resistive component is not significant in this situation. The controlling impedance is the capacitance of the rod to ground. This capacitance may be calculated by the formula,

$$C = (55.63 * h)/(\ln(h/a)-1)$$

where (h) is the length of the rod and (a) is its radius, both in meters. For a typical 41-inch rod, this is 12 pF. This capacitance is significant because it combines with the total input capacitance of the amplifier to form a voltage divider. It can quickly be seen that if the FET input capacitance and circuit stray total 12 pF, there will be a 6dB loss through this stray capacitance. Even if the total input capacitance were reduced to 4 pF, there would be a 2.5dB loss.

Finally, *the interaction of the rod with the ground* must be understood. The theoretical understanding of the rod assumes that it operates in reference to an infinite ground at a zero-volt potential. The closer the test situation is to this scenario, the more accurate the readings. A small vestigial ground is provided with many units in the form of a counterpoise. Care should be taken to reference this counterpoise to true ground. The procedures for this are carefully explained in various standards. If the counterpoise is not well grounded, an impedance may be built up through the cabling and other instrumentation. Reading differences of as much as 20dB can be found with ungrounded counterpoises. This will be particularly true of readings taken in a screen room and for all rod antennas regardless of their design.

Another counterpoise problem is the potential for positive feedback. Good amplifier design calls for the output to be 180 degrees out from the input. This output typically drives the center conductor of a coaxial cable. The shield then carries a return current, which is 180 degrees out of phase with the output signal. So the shield current is in phase with the input. If the shield and the counterpoise are tied through the body of the unit, then the counterpoise will receive some of this current. If the counterpoise does not have an extremely low inmpedance to ground, then this return current can drive a potential on the counterpoise in phase with the input, resulting in errant readings. One solution to this problem is an internal common mode choke placed to manage the return current flow and so to minimize the impact of an inadequate test setup. However, a proper test configuration will always be critical to ensure precise measurement accuracy.

Also of concern is contribution of edge effects from the vestigial ground plane. Most theory is developed on the assumption of one infinite ground plane. How using a small vestigial ground plane or counterpoise affects the theory has not been well studied to date. Even more complicated is the effect of this vestigial ground plane when the unit is used in a screen room with ground planes on all sides. In practice, the best results are obtained by tightly typing the counterpoise to the screen room through an ultra-low impedance ground strap. This at least assures that at the lower frequencies, all of these surfaces are at an equal potential.

THE PRE-AMPLIFIER

The pre-amplifier may be considered as having two stages: the first stage providing impedance transformation and current gain; the second stage providing voltage gain and impedance matching to a 50-ohm output.

The first stage of the pre-amplifier typically contains an n-channel JFET and an NPN bipolar silicon transistor. Through the use of extremely precise layout techniques, careful parts selection and feedback to virtually eliminate the Miller effect, the total input capacitance is kept extremely low. This low capacitance, in turn, allows for an extremely high input impedance. It is the input impedance which determines the effective low frequency cutoff of the unit. Careful design and layout management can result in low frequency cutoffs as low as 30 Hz. In fact, artificial limits may be needed to protect the unit in situations where overloading from power frequencies would be a problem.

The second stage is used for voltage gain and to match the first stage output to the 50 ohms of the output cable. This stage is typically designed using bipolar devices in a common emitter/common collector combination. Design for low noise is critical in both stages. Poor component selection or design in any stage may cause a noise problem which cannot be overcome in later stages.

The dynamic limits of the active rod are set by the amplifier. Sensitivity is determined by the noise developed in the first stage. The ultimate limit on sensitivity is determined by the thermal noise generated by the input impedance. The impedance presented to the amplifier by the rod is almost entirely capactive. A 41-inch rod typically presents an impedance of about 12 pF, so the input impedance presented to the amplifier will decline with increasing frequency. At the low frequencies, where the input impedance is high, the thermal noise generated by this impedance will also be high. If the input impedance of the amplifier is lowered to reduce thermal noise, then the rod will be loaded down and lose sensitivity. This combination of thermal noise and rod impedance sets an ultimate limit on the sensitivity achievable by active rod antennas. The sensitivity of most active rods improves with frequency in direct relation to the declining input impedance.

A common mistake made in regard to sensitivity is to ask what the noise figure of an active rod is. Noise figure is defined as the ratio of the output noise of a unit over the output noise expected solely due to the thermal noise of the resistance of the input impedance. Since the input in the case of a rod is primarily reactive, the definition literally has no meaning. What is useful is to determine what the minimum discernible signal of a unit is. That is, what is the smallest signal which can be seen in the presence of the amplifier noise? There is a trick here. The smallest signal seen above the noise in a rod antenna is not just determined by the noise of the amplifier. A signal is drained away through capacitive loss before it reaches the amplifier. An amplifier with more noise may actually be more sensitive if it also loses less signal to capacitance at the input (Figure 2). The small spectrum components can be seen over the higher noise of unit B. The lower noise of unit A would make one think more could be seen with this unit. However, due to front end capacitance-to-ground, it loses these low-level signals before they ever get to the amplifier.

The upper limit of the dynamic range is determined by the ability of the gain stage to amplify a signal. The gain stages capable of handling field strengths of 0.7 V/m are available. Impulsive type signals saturate

the amplifier in such a way as may not be immediately obvious. An impulse signal presents the amplifier with signals at a number of frequencies all in phase with each other, so measurement of the field strength at any one frequency will not appear to be very high. However, the amplifier is being called upon to amplify signals at many frequencies simultaneously. In the time domain, the amplifier would be seen to be presented with quite a large instantaneous demand for power. The result is that impulsive signals appear to saturate the amplifier at much lower signal levels. The same unit which will handle 0.7 V/m narrowband has been measured to begin going non-linear at 63dBμV/m/MHz.

A frequency-independent saturation indicator should be provided on any active antenna to protect the user from taking false readings. This indicator will eliminate many false readings due to non-linear operation. However, some types of impulse signals may not trigger an indicator properly. The user must, therefore, be careful to observe the published limits for any unit being used.

Because saturation is a function of the amplifier second stage, an internal attenuator may be used to increase the dynamic range of a unit. A carefully designed attenuator will allow the user working in a high-field environment to continue to use the antenna without suffering saturation problems. However, there will be a loss of sensitivity when such an attenuator is used. An attenuator must be placed before the gain stage; after the gain stage of the unit will do no good since the input to that stage is unaffected.

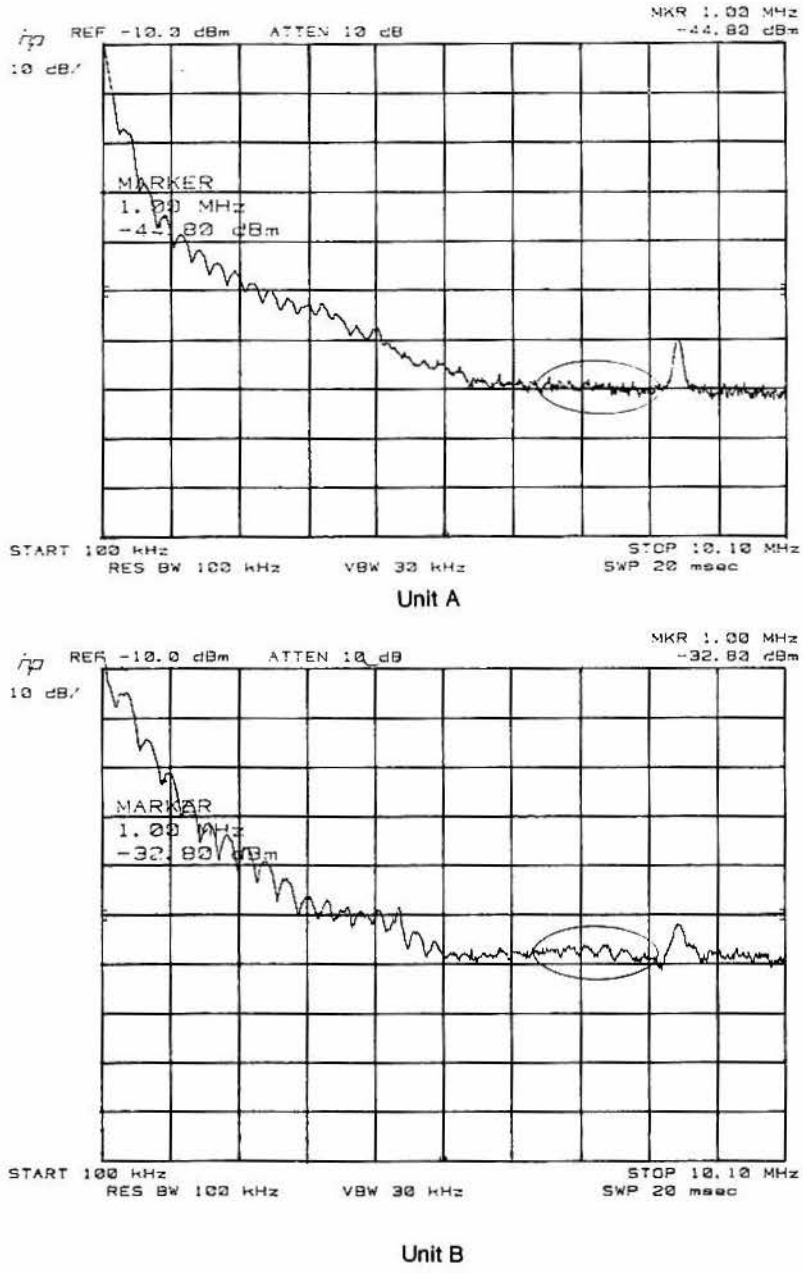
MKR 1.00 MHz
REF -10.3 dBm ATTEN 10 dB -44.80 dBm
10 dB/
MARKER
1.00 MHz
START 100 kHz STOP 10.10 MHz
RES BW 100 kHz VBW 30 kHz SWP 20 msec
Unit A
MKR 1.00 MHz
REF -10.0 dBm ATTEN 10 dB -32.80 dBm
10 dB/
MARKER
1.00 MHz
START 100 kHz STOP 10.10 MHz
RES BW 100 kHz VBW 30 kHz SWP 20 msec
Unit B

Figure 2. The minimum discernible signal is determined by the front end capacitive loss and the amplifier noise. Note should be taken that even though unit A has a lower output noise, the low level signal components are lost due to capacitance to ground. Unit B has a better balance between stray capacitance and amplifier noise, and so is able to reveal these low level spectral features.

THE ANTENNA FACTOR

The antenna factor provided with the unit is simply a ratio of the field strength presented to the unit to the voltage output from the unit at that field strength. The field strength may be derived by adding the antenna factor to a given output. The antenna factor in an active rod combines several factors: the first factor is the 6dB required to normalize the rod to one meter; the next is the measured capacitive loss at the front of the unit. Losses as low as 2dB are achievable with meticulous design. Then, there is the open circuit gain of the amplifier itself. Commonly, 7 to 15dB of gain is used. Finally, 6dB is required if a true conjugate match to the 50-ohm output is used. The antenna factor is the sum of these factors. A typical result might be:

- −6dB Rod Normalization
- −4dB Capacitive Loss
- + 15dB Pre-amplifier Gain
- −6dB 60-ohm Matching Loss
- −1dBGain Over Field Strength

or an antenna factor of 1dB.

CALIBRATION PROCEDURE

A recommended calibration method for active rods is the equivalent capacitance method of calibration. In order to check the calibration, a calibration test fixture is required (Figure 3). This fixture contains a resistive "T" and a capacitor. The "T" allows for accurate reading of the input to the fixture. The capacitor feeds the amplifier through the same impedance as the 41-inch rod pre-

sents to it. The result is a simple, yet extremely accurate, calibration.

Periodic checks of a unit's performance are recommended. In order to calibrate the unit, the calibration fixture is attached and grounded to the unit housing through one of the counterpoise-mounting holes. A signal source is placed on one leg of the fixture and a receiver on the other leg. Then, the output of the unit is terminated with 50 ohms. The input signal strength is read. The input signal strength measured through the calibration fixture must have 11dB added to it. This 11dB is composed of 6dB required to normalize the rod to one meter and 5dB of signal loss through the resistive divider in the "T". After the input loss is read, the receive cable is moved to the output of the unit and a 50-ohm load is placed on the now open leg of the calibration fixture. The unit output is read (Figure 4 shows a typical fixture). The antenna factor is the input plus 11dB, minus the output, both readings assumed to be logarithmic.

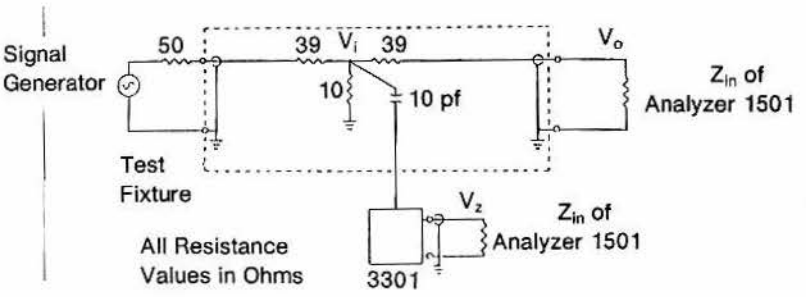

Figure 3. Rod Antenna Calibration Test Fixture.

Example

Assuming a reading is taken with a one MHz signal input to the calibration fixture: the input is read at 50dBμV and the output is read as 59dBμV. The antenna factor is then the input plus 11dB, minus the output, or

$$50\text{dBV} + 11\text{dB} - 59\text{dB}\,\mu\text{V} = 2\text{dB}$$

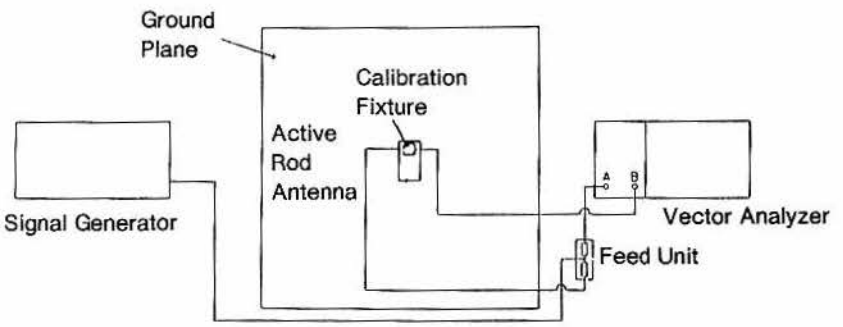

Figure 4. Rod Antenna Calibration Test Setup.

SUMMARY

The active 41-inch rod is not a trivial device. Although relatively simple in its basic concept, the interaction of its different facets makes the design of such a unit very demanding. The interfaces between the test setup, rod, amplifier and measurement instrumentation must all be understood and properly implemented if accurate readings are to be obtained. This article has reviewed the physics of the various components of the active rod and point out some common mistakes which can cause erroneous readings. However, when properly used, an active rod is a useful and even elegant E-field transducer. ■